Photovoltaic Czochralski Silicon Module Improvements

Highlights

- Reduced manufacturing cost by more than 15%
- Increased manufacturing yield by more than 20%
- Received ISO 9001 certification as recognition of procedures instituted to assure the production of high-quality modules
- Introduced several new lower-cost cell and module products

This Siemens Solar Industries project is part of the 1995 solicitation of PVMaT—a cost-shared partnership between the U.S. Department of Energy and the nation's PV industry to improve the worldwide competitiveness of U.S. commercial PV manufacturing.

PVMaT Fact Sheet
Photovoltaic Manufacturing Technology

Siemens Solar Industries

Goal

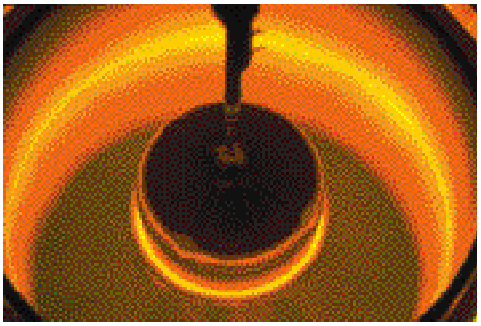
The goal of Siemens Solar Industries under the 1995 PVMaT solicitation was to reduce module manufacturing costs by 18% through continued advances in module design and manufacturing processes.

Background

For two decades, Siemens Solar has made PV modules with single-crystal silicon produced by the Czochralski (Cz) method. Such modules have higher conversion efficiencies than those made with polycrystalline silicon or thin-film materials, and they dominate the PV power market. Although this is a "mature" PV technology, there is still room for improving the technology, reducing manufacturing costs, and expanding the market.

Technical Approach

In the Cz method, a single-crystal silicon “seed” is touched to molten silicon heated in a crucible. The seed is slowly withdrawn, causing a raised meniscus of molten silicon to form between the seed and the melt. As the seed is slowly pulled from the melt, the silicon meniscus crystallizes, eventually forming a cylindrical ingot of single-crystal silicon.



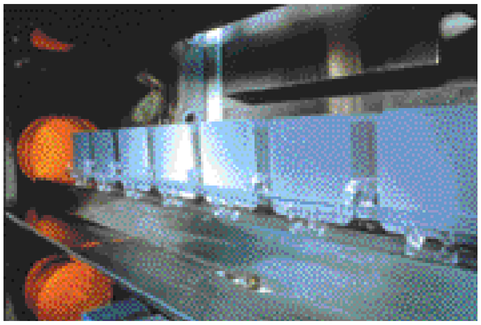
Siemens Solar/PIX06135

Siemens manufactures high-efficiency solar cells from single-crystal ingots drawn from a silicon melt.

The solidified ingot is cut into wafers, which are then processed into PV cells. The boron-doped wafers are subsequently doped with phosphorus to initiate the photovoltaic effect. An anti-reflective oxide coating is applied to each wafer to further enhance light absorption. Electrical contacts are formed by using an inexpensive screen-printing process that applies silver paste to the front and back of the solar cell.

Once processed, the cells are tested and electrically connected to form strings. Modules are produced by imbedding the cell strings in ethylene vinyl acetate between a tempered front-glass and a multilayer backsheet.This construction protects the cells against moisture, ensures ultraviolet stability, and provides electrical insulation.

At the end of this production process, the module is fitted with an aluminum frame. Bypass diodes in the junction box protect cells from excess local heating in case partial shading of the module occurs. The junction box also allows easy module connection using cable, conduit, or wire.



Siemens Solar/PIX06142

Czochralski silicon wafers enter a furnace for phosphorus doping.

Results

To reach its goal of reducing module manufacturing costs by 18%, Siemens analyzed the cost and design of its modules, improved yield and productivity, and instituted manufacturing systems to improve module reliability.

Analysis

As a first step in reducing costs, Siemens analyzed the factors that dominate the cost in module manufacturing. The analysis persuaded the company to redesign modules with larger cells and a less-expensive junction box. These changes have now been introduced into high-volume production in Siemens' plant in Camarillo, California.

The new module design takes advantage of low-cost materials in the junction box and in framing. At high manufacturing volumes, the new design reduces per-watt costs by more than 15%, compared to the standard Siemens M55 module.

Yield

Manufacturing yield is a powerful cost driver of cells used in a module, of module materials, and of module manufacturing labor. Siemens closely monitored manufacturing yield and categorized the types of losses in wafering, cell fabrication, and module fabrication. The company determined that the dominant yield loss was due to mechanical breakage of wafers, followed by material loss due to sawing ingots into wafers.

To reduce yield loss due to mechanical breakage, Siemens improved tracking, developed better equipment to handle wafers, educated operators, and experi-mented to find the dependence of wafer breakage on material properties. These improvements boosted line yields by more than 15% for the company's 103-mm^2 cells and by more than 20% for its 125-mm^2 cells.

To reduce sawing losses, Siemens installed saws with thinner blades, which increased wafer production from 29 wafers to 47 wafers per inch of ingot.

Module reliability

To improve product reliability and quality, Siemens instituted several management, manufacturing, and quality-control procedures.

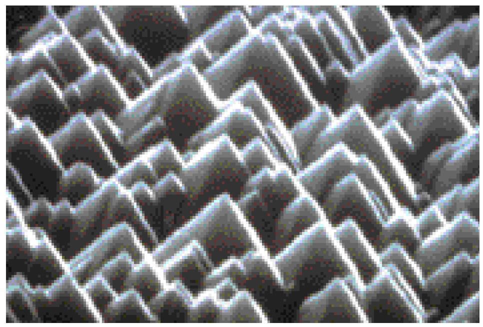
First, Siemens established and documented state-of-the-art practices for manufacturing procedures, operator training, and maintenance and calibration. In March of 1996, this effort resulted in the company's Camarillo plant receiving ISO 9001 certification—an internationally recognized set of standards for processes that ensure the quality of products.

Second, working with NREL, Siemens developed a system to measure minority-carrier lifetimes of single-crystal silicon ingots—to ensure that high-quality materials will be used for making wafers.

Third, the company instituted Statistical Process Control (SPC) to help assure quality in many areas of manufacturing, from soldering to diffusion processes. SPC, for example, has enabled the company to improve its control of dopant diffusion, leading to a greater statistical average of high-quality wafers and cells.

Fourth, Siemens now regularly subjects its modules to qualification testing, which is a series of tests designed to indicate a module's quality and reliability.

These and other improvements have helped Siemens improve the reliability of its modules to the point where the company now offers a 25-year warranty on its modules.



Siemens Solar/PIX06140

Siemens gives wafer surfaces a pyramidal texture to increase light absorption.

Company Profile

STI began in 1975 with seven people. In 1977, Atlantic Richfield bought STI, and renamed it ARCO Solar.

In 1990, Siemens AG of Germany purchased the company from Atlantic Richfield, renamed it Siemens Solar Industries, and dedicated itself to carrying PV into the next century and making it viable for large power markets.

In 1996, Siemens Solar reached a milestone when it passed the 100-MW mark—having shipped more than 100-million watts of modules in its 20-year history. This is about one-fifth of the world's total installed PV power.

Today, Siemens has manufacturing facilities in Munich, Germany, and in Camarillo, California—where the main plant has been for nearly 20. It ships about 25 megawatts of PV modules a year and employs nearly 500 people.

References

Jester, T.; "PV Cz Silicon Manufacturing Technology Improvements," Final Subcontract Report, 1 April 1992–31 May 1995, NREL/TP-411-20016 (Oct 1995).

King, R.R.; Mitchell, K.M.; Jester, T.L. "Improvements in Cz Silicon PV Module Manufacturing," in *AIP Conf. Proc. 394, 14th NREL PV Program Review*, Lakewood, CO, 1997, pp. 433–444.

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